CODE's multi-GNSS orbit and clock solution – status 2015

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COST ES1206 Workshop, 11-14 May 2015,
Thessaloniki, Greece

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- CODE MGEX orbit solution
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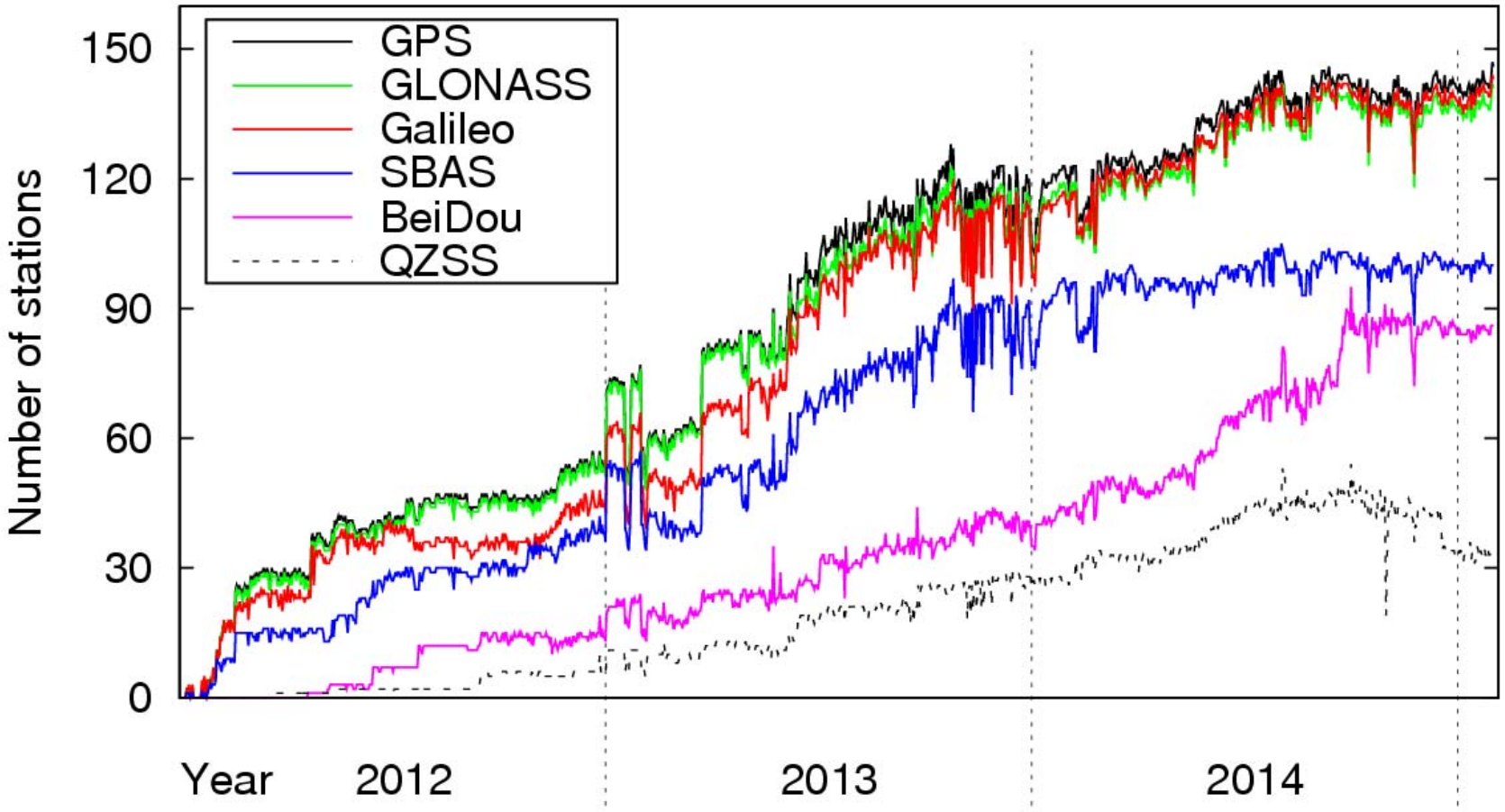
- Impact of CODE‘s new radiation pressure model
- Summary and outlook

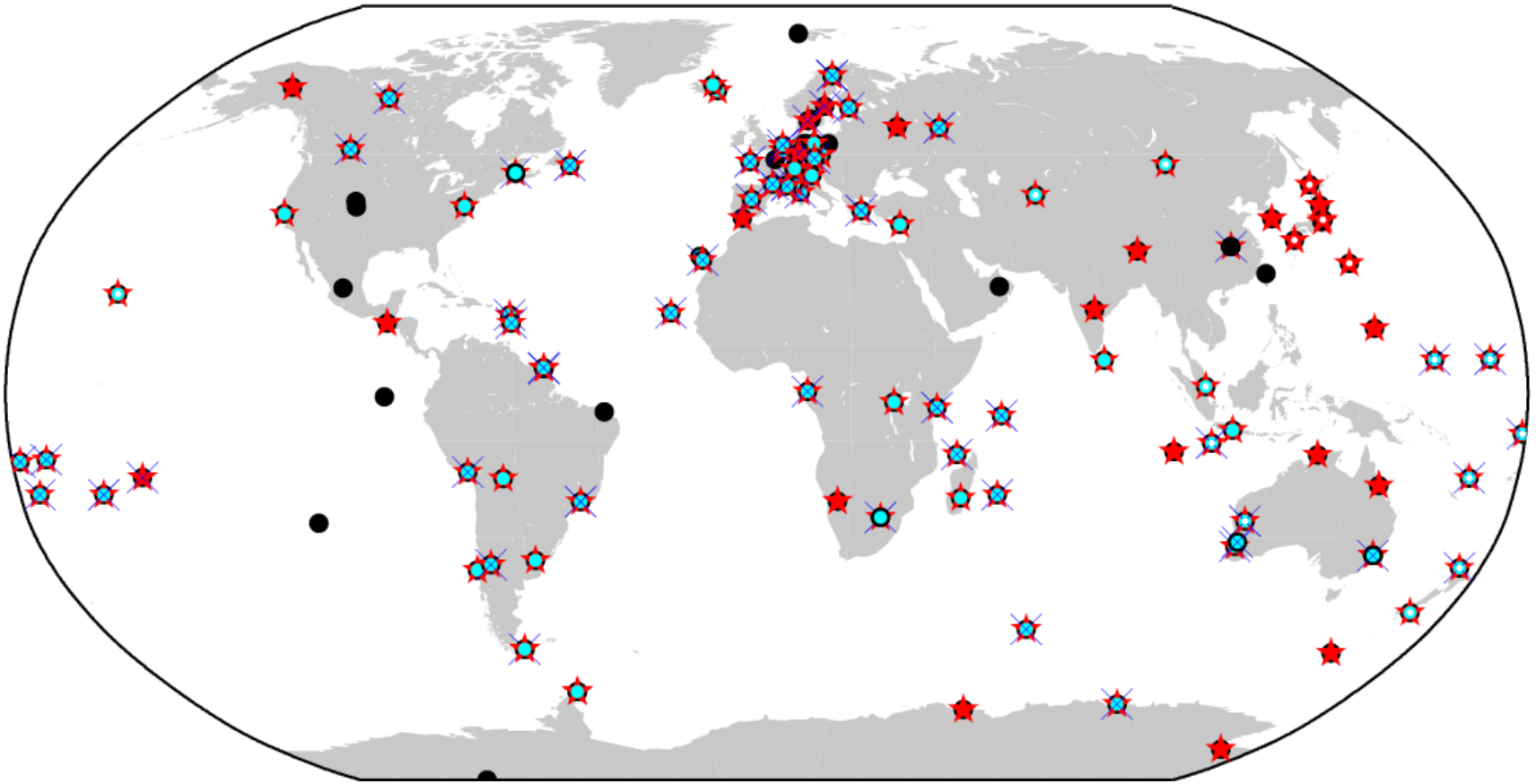
MGEX data monitoring

Number of stations providing daily RINEX3 files included in CODE's raw data monitoring (data sources IGS-MGEX and EPN)



Tracking network

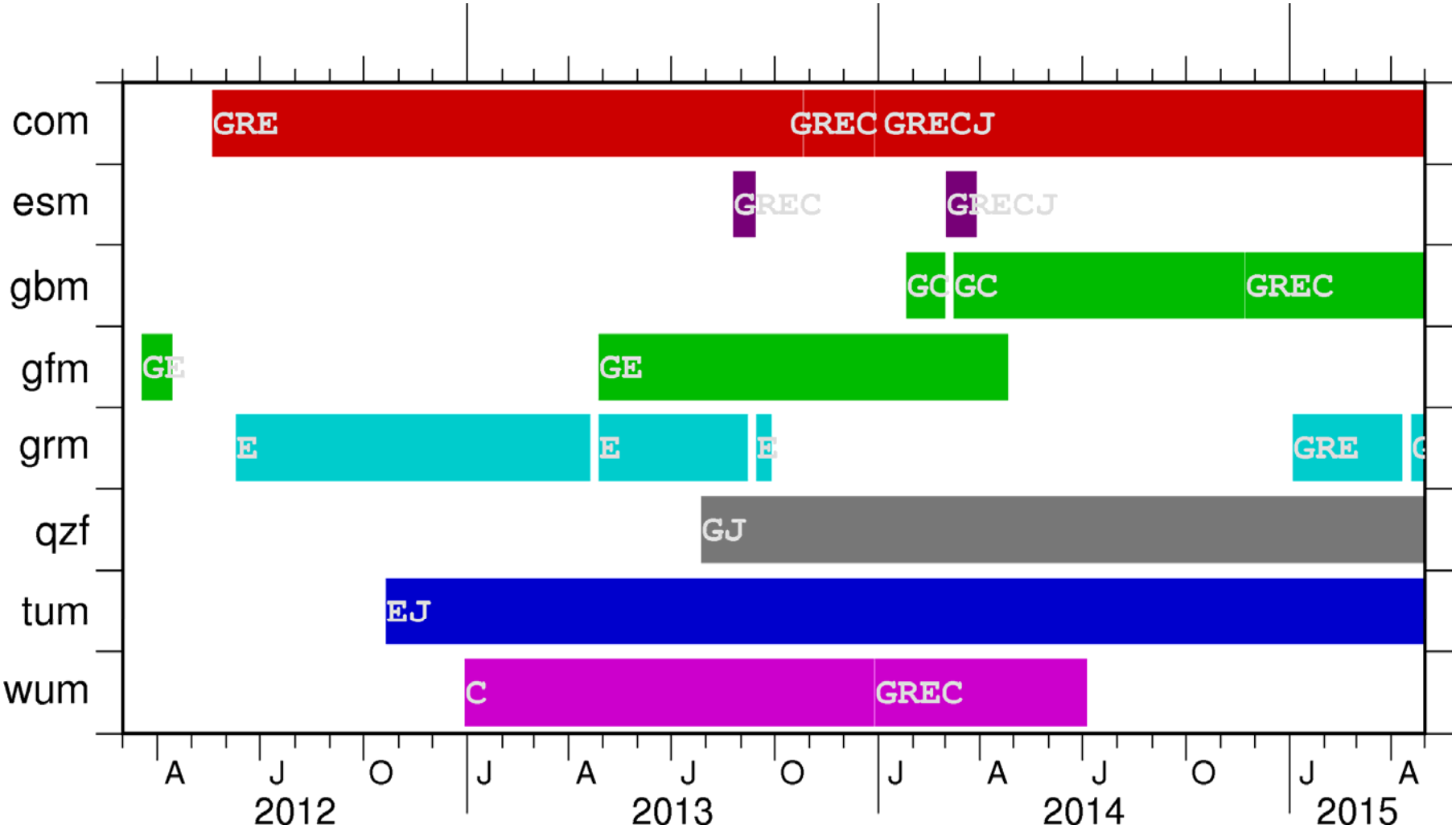
Station distribution for orbit solution (DOY 15/030)



MGEX data monitoring

- Growing number of stations providing daily RINEX3 files
- No substantial problems with RINEX3 format and data distribution chain noticed from AC side
- Galileo and QZSS are well tracked (apart from firmware issues of Trimble NetR9 receivers reported by DLR)
- Still large gaps for BeiDou (especially in central and east Asia => relevant for IGSO and GEO satellites)
- Public access to MGEX monitoring results via AIUB FTP:
  => ftp://ftp.unibe.ch/aiub/mgex/

MGEX products availability



Status: 01-May-2015

Satellite system IDs according to the content of the precise orbit files at ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/

CODE MGEX orbit solution

GNSS considered:	GPS + GLONASS + Galileo + BeiDou (MEO+IGSO) + QZSS (70 SV)
Processing mode:	post-processing / 2 weeks delay (since 2015)
Timespan covered:	GPS-weeks 1689-1841 (DOY 12/146-15/115)
Number of stations:	130 (GPS), 110 (GLONASS), 85 (Galileo); 55 (BeiDou); 20 (QZSS)
Processing scheme:	double-difference network processing (observable: phase double differences)
Signal frequencies:	L1+ L2 (GPS + GLO+ QZSS); E1 (L1) + E5a (L5) GAL; B1 (L1) + B2 (L7) BeiDou
Orbit characteristic:	3-day long arcs; RPR: ECOM / ECOM2 (since 2015)
Reference frame:	IGS08 (until week 1708); IGb08 (since week 1709)
IERS conventions:	IERS2003 (until 1705); IERS2010 (since 1706)
Product list:	daily orbits (SP3) and ERPs
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/
Designator:	comwwwwd.???.Z

CODE MGEX clock solution

GNSS considered:	GPS + GLONASS + Galileo + BeiDou + QZSS (70 SV)
Processing mode:	post-processing / 2 weeks delay (since 2015)
Timespan covered:	GPS-weeks 1710-1841 (DOY 12/288-15/115)
Number of stations:	130 (GPS), 35 (GLO), 45 (Galileo); 50 (BeiDou); 20 (QZSS)
Processing scheme:	zero-difference network processing (observable: code+phase undifferenced)
Signal frequencies:	L1+ L2 (GPS + GLO+ QZSS); E1 (L1) + E5a (L5) GAL; B1 (L1) + B2 (L7) BeiDou
A priori information:	orbits, ERPs, coordinates, and troposphere from CODE MGEX orbit solution introduced as known
Reference frame:	IGb08
IERS conventions:	IERS2010
Product list:	epoch-wise (300s) satellite and station clock corrections in daily clock RINEX files; daily inter-system biases for mixed stations in Bernese DCB and BIAS-SINEX (BIA) format
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/
Designator:	comwwwwd.???.Z

CODE MGEX data processing: Summary

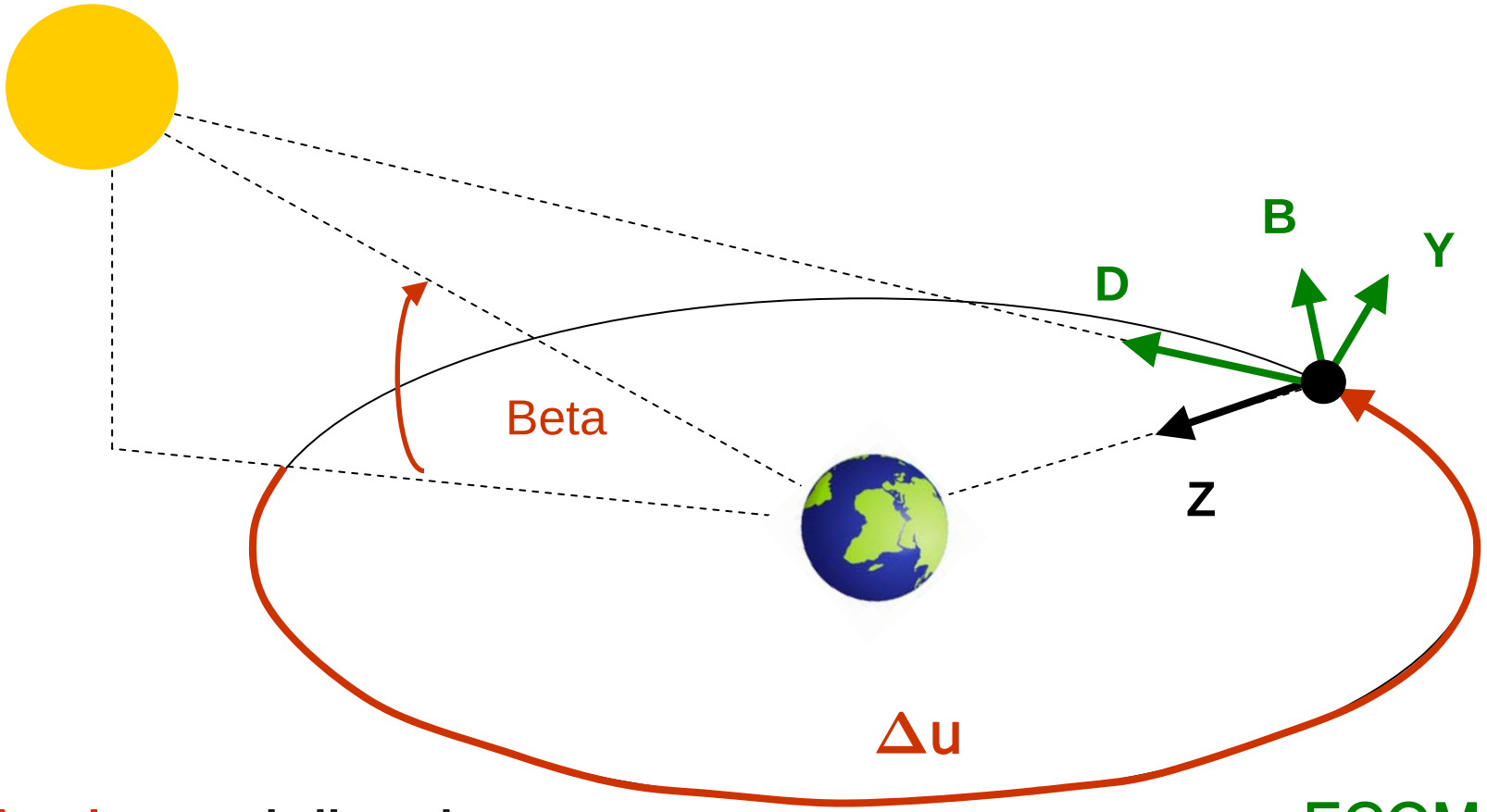
- CODE provides an MGEX-based, fully integrated, five-system orbit and clock solution
- GNSS included:

  GPS+GLONASS+Galileo+BeiDou (MEO, IGSO)+QZSS
- Orbit and coordinate solution: double-difference
- Clock solution: zero-difference
- CODE MGEX products are available via CDDIS FTP => ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/

CODE MGEX data processing: What is new?

- GNSS added: **QZSS; GLONASS** clocks and IFB
- Adapted station selection
- Reprocessing for 2014 => server updated in January 2015
- ECOM2 RPR model (Arnold et al., 2015 => presentation of Arnold Yesterday) implemented for MGEX since early 2015 (this concerns all submitted products based on data of 2015)
- Product delivery switched from batch-wise to regular mode (delay of about 2 weeks)
- Estimation of Galileo antenna PCO started (only nadir-dependent so far)

Orbit description and Yaw attitude



Angles and directions:

Beta: Elevation of Sun above orbital plane

Δu: Argument of latitude

Z: Direction satellite -> Earth (antenna direction)

ECOM axes:

D: Direction satellite -> Sun

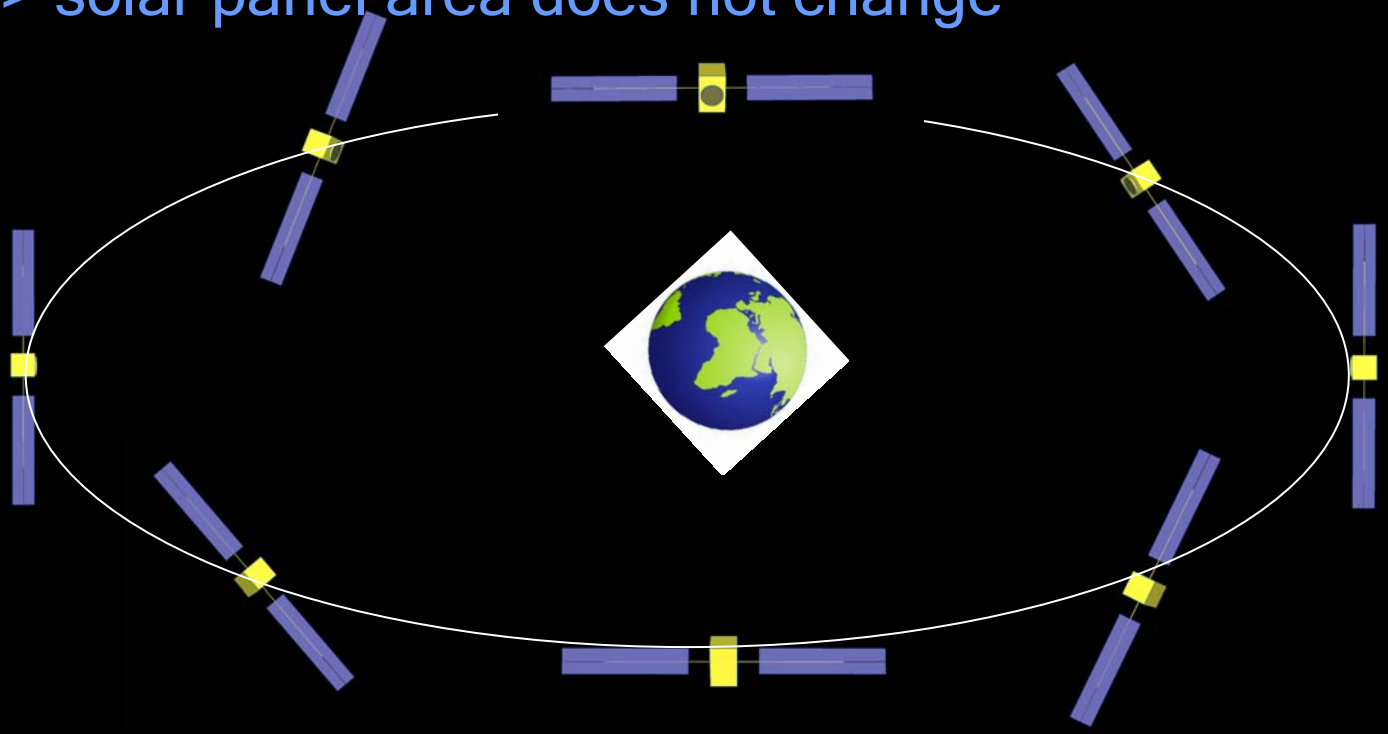
Y: Solar panel axis

B: Third ECOM axis

Solar radiation pressure

Satellite cross-section as seen from the Sun (Beta ≈ 30°) during one orbital revolution:

=> solar panel area does not change



=> but: cross-section of long satellite bodies w.r.t. the Sun varies

New Empirical CODE radiation pressure Model

- MGEX-reprocessing for 2014 using ECOM (5 RPR par.; Springer et al., 1999) vs. ECOM2 (9 RPR par., Arnold et al., 2015)
- Validation with SLR residuals and satellite clock corrections
- The new ECOM takes into account the periodically changing cross section of the satellite body wrt. the Sun

=> Improvements expected for GLONASS, Galileo, QZSS

ECOM1 (old):

$$D(u) = D_0$$

$$Y(u) = Y_0$$

$$B(u) = B_0 + B_C \cos(u) + B_S \sin(u)$$

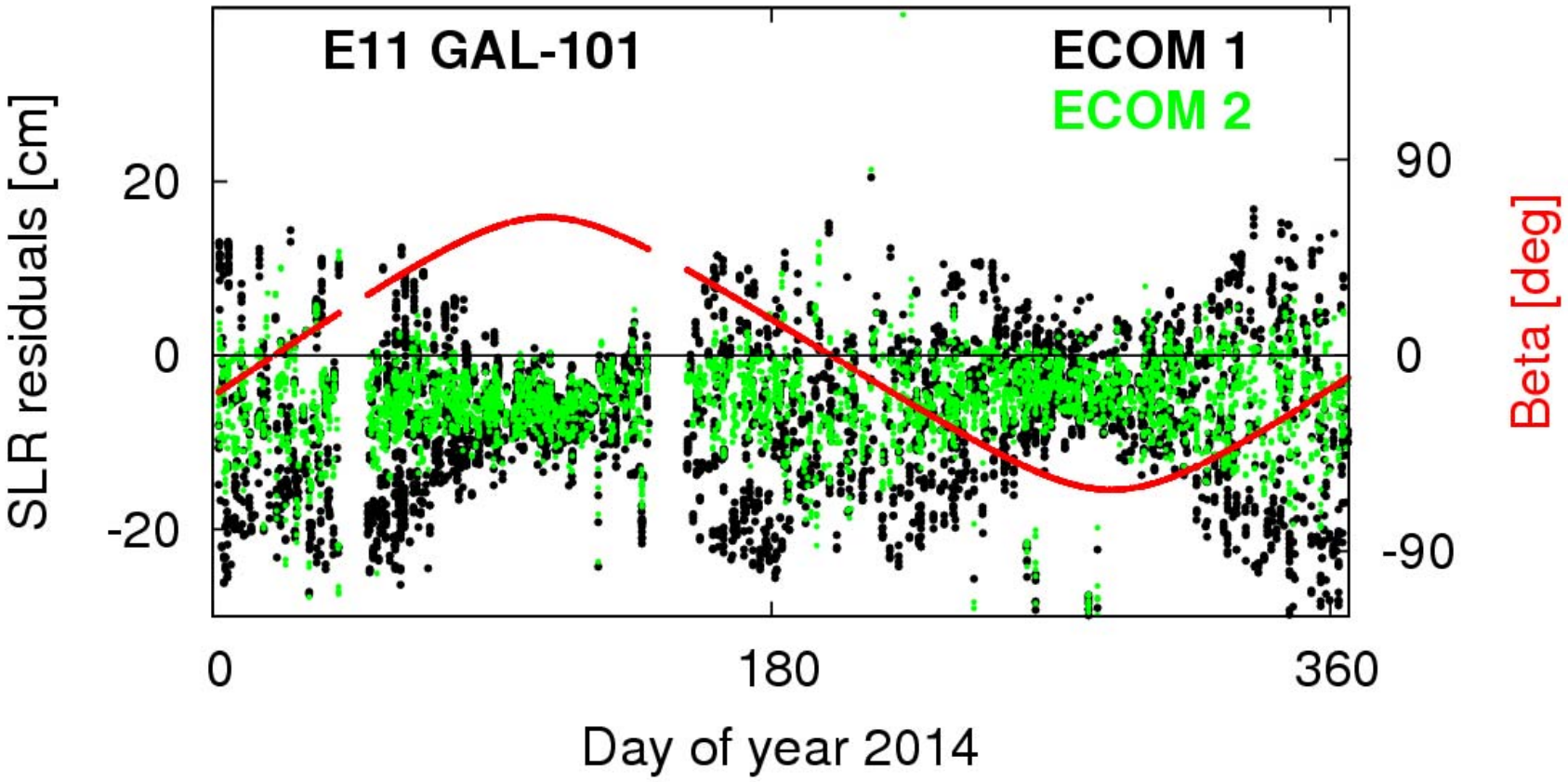
ECOM2 (new):

$$D(u) = D_0 + D_{2C} \cos(2\Delta u) + D_{2S} \sin(2\Delta u) + D_{4C} \cos(4\Delta u) + D_{4S} \sin(4\Delta u)$$

$$Y(u) = Y_0$$

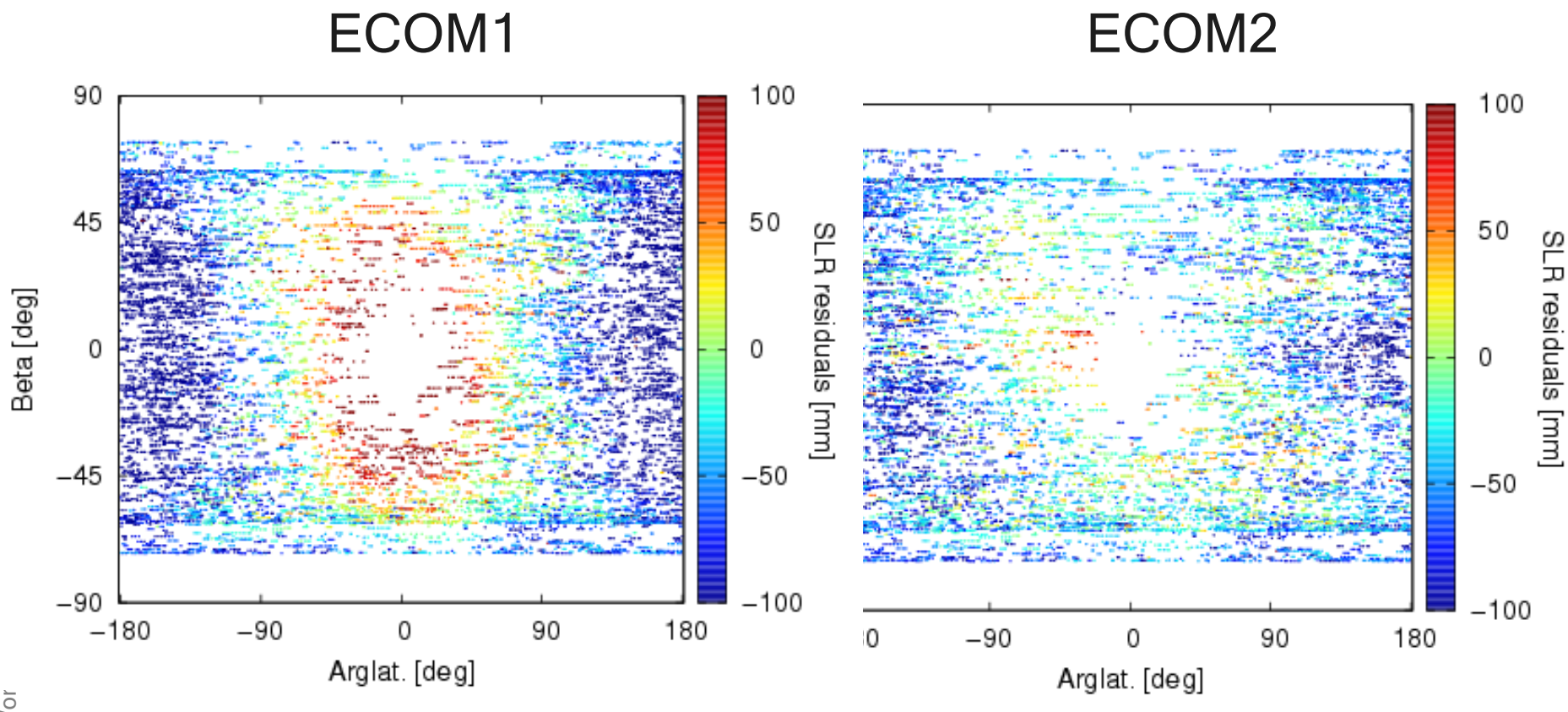
$$B(u) = B_0 + B_C \cos(\Delta u) + B_S \sin(\Delta u)$$

Impact of new ECOM on Galileo orbits



=> Significant reduction of size and dependency of SLR residuals on the Beta-angle (elevation of the Sun above the orbital plane)

Impact of new ECOM on Galileo orbits



=> Reduced amount of SLR residuals with extremely large or small values close to or opposite to the direction of the Sun

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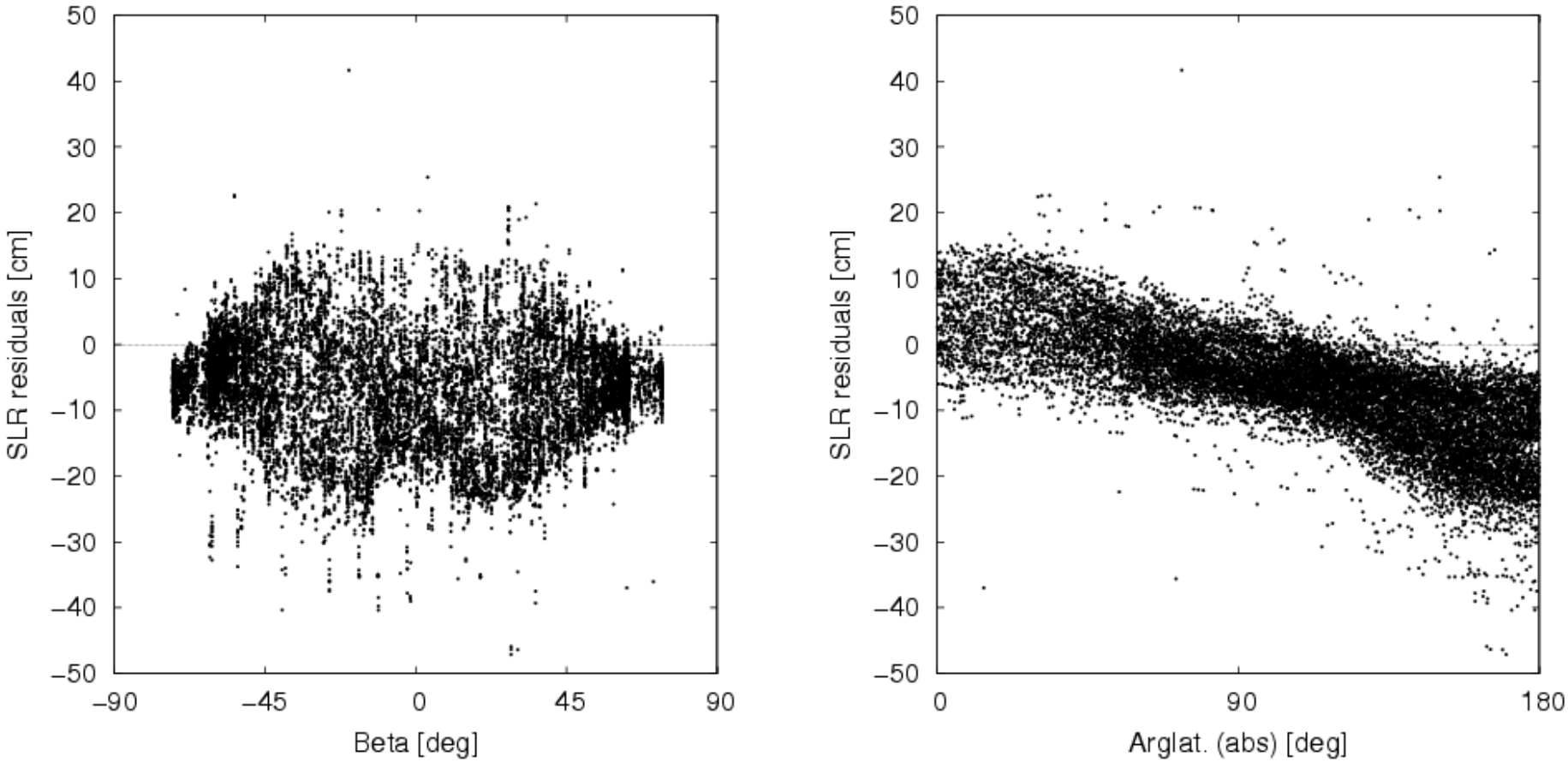
Impact of new ECOM on Galileo orbits



ECOM1 (all Galileo satellites):

=> Large SLR residuals for low and medium Beta angles and for argument of latitude around 0 and +-180 degrees

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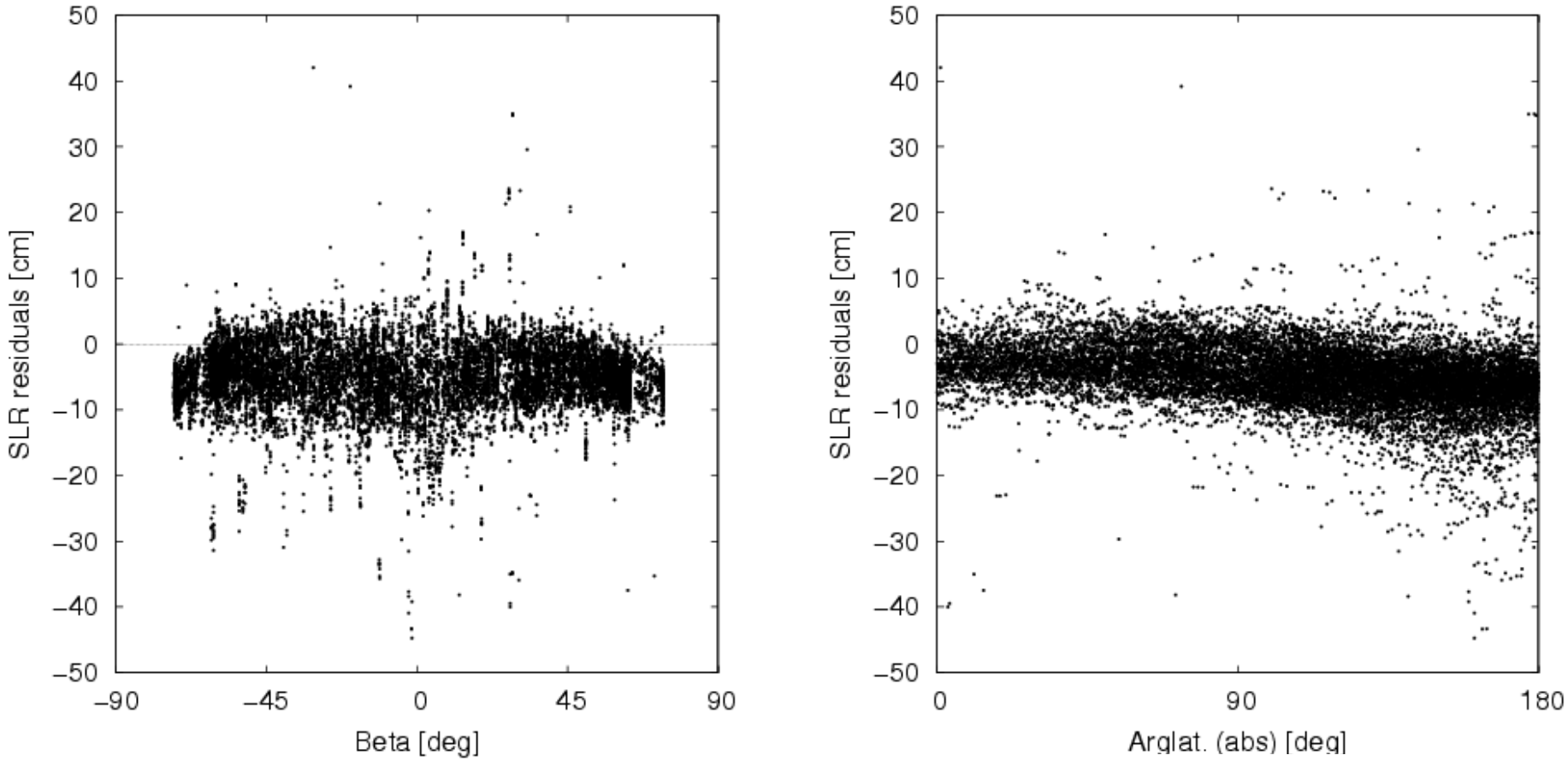
Impact of new ECOM on Galileo orbits



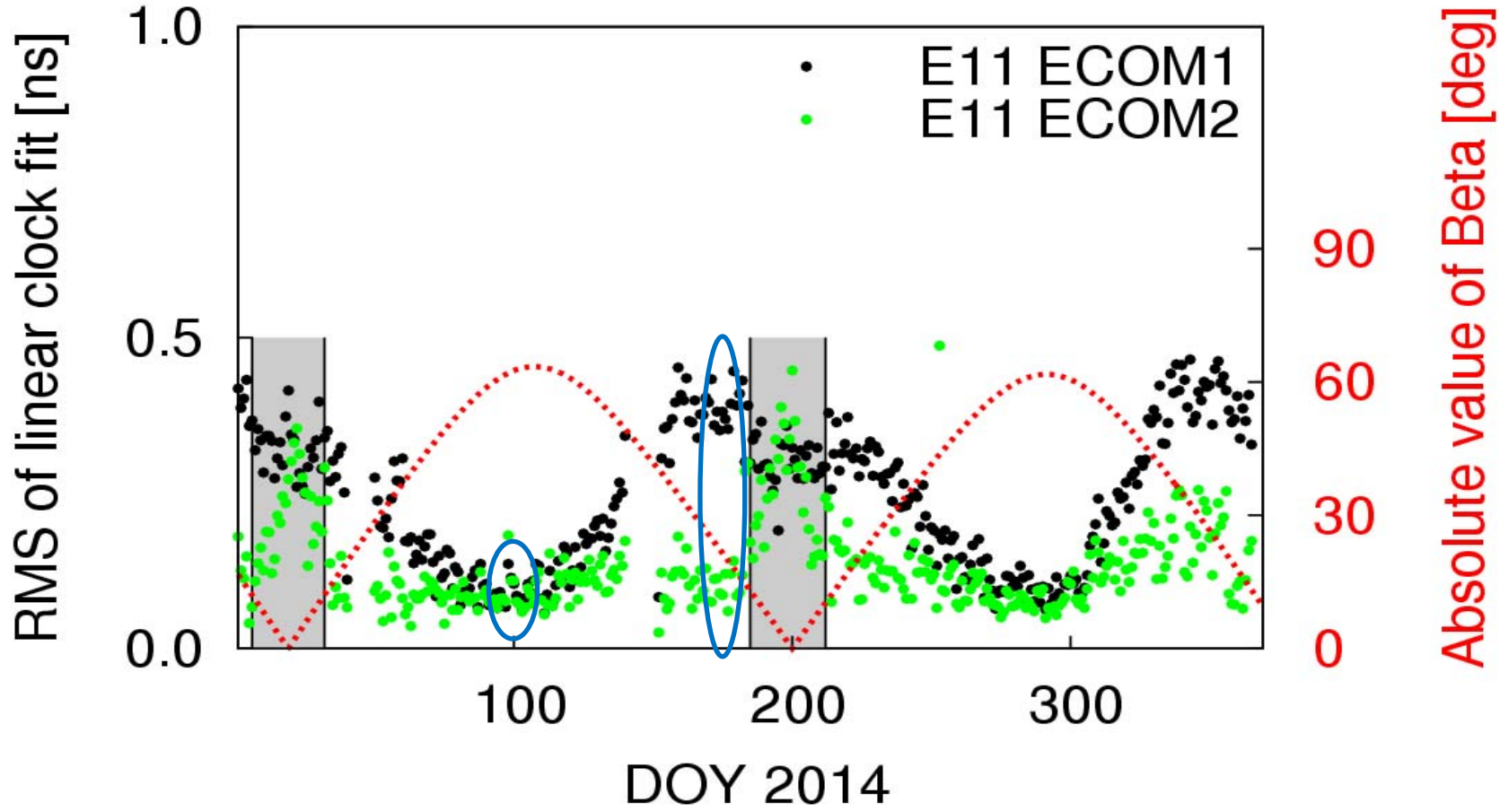
ECOM2 (all Galileo satellites):

=> Systematics in the SLR residuals are significantly reduced

=> SLR offset of about 5 cm (less for FOC) remains

L. Prange et al.: COST ES1206 W

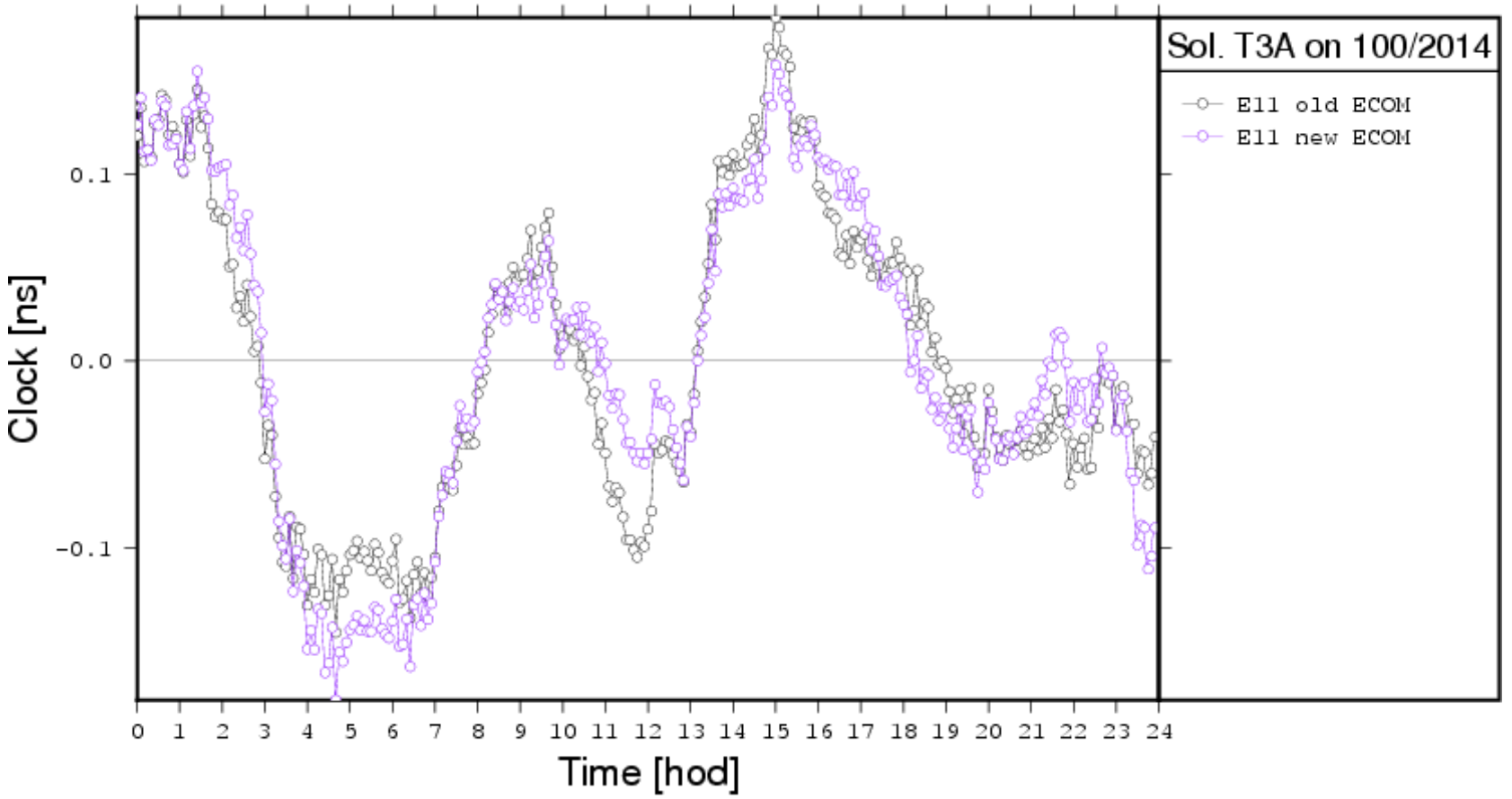
Impact of new ECOM on Galileo clock corrections



=> Significant reduction of Beta angle dependency

=> Pronounced signal remains during eclipse season or close-by (=> impact of mis-modelled attitude?)

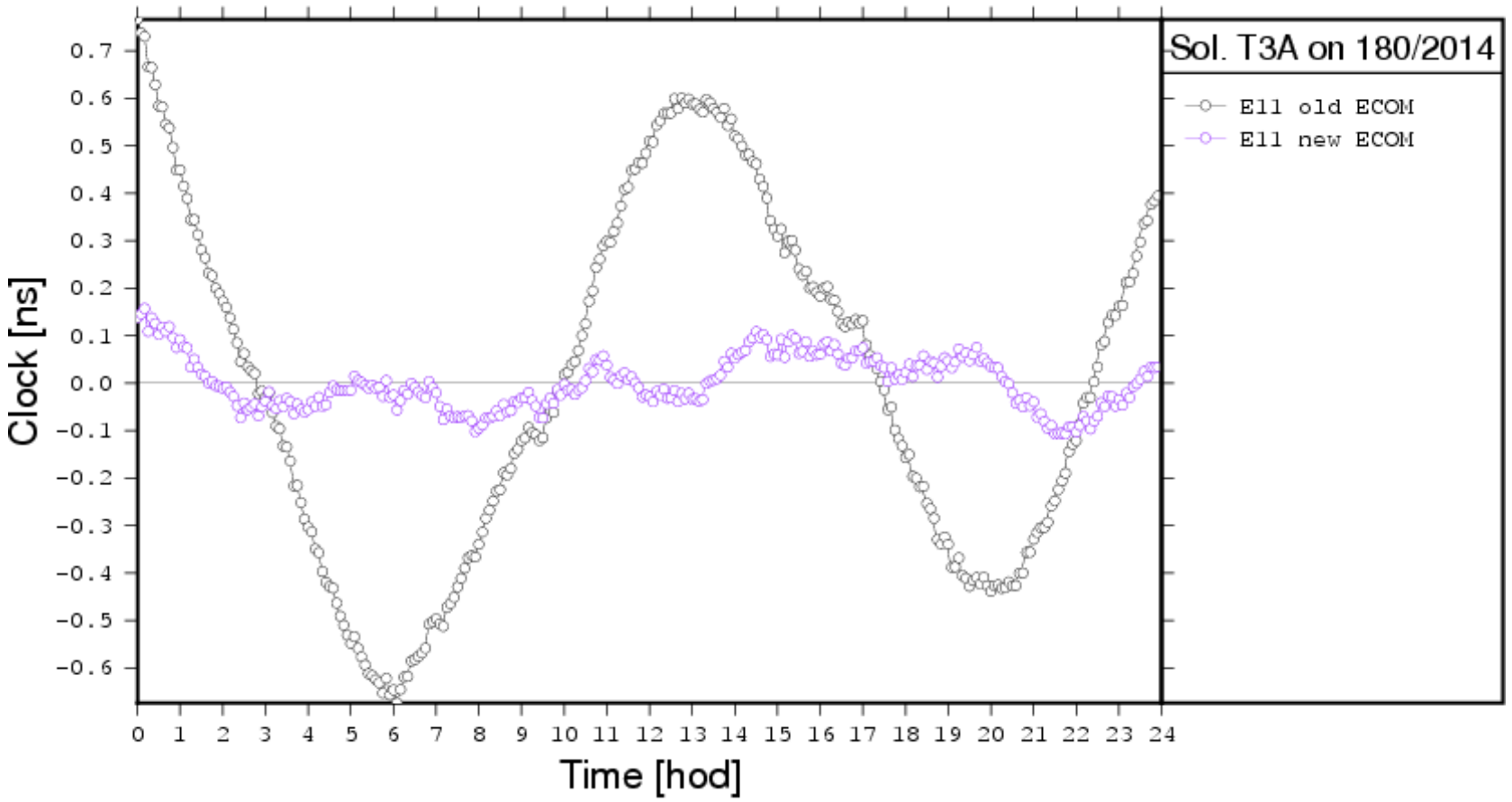
Impact of new ECOM on Galileo clock corrections



DOY 14/100: Beta-angle is large (i.e., cross-section of satellite body wrt. the Sun is more or less constant)

=> No improvement (variation in clock signal about +- 0.15 ns)

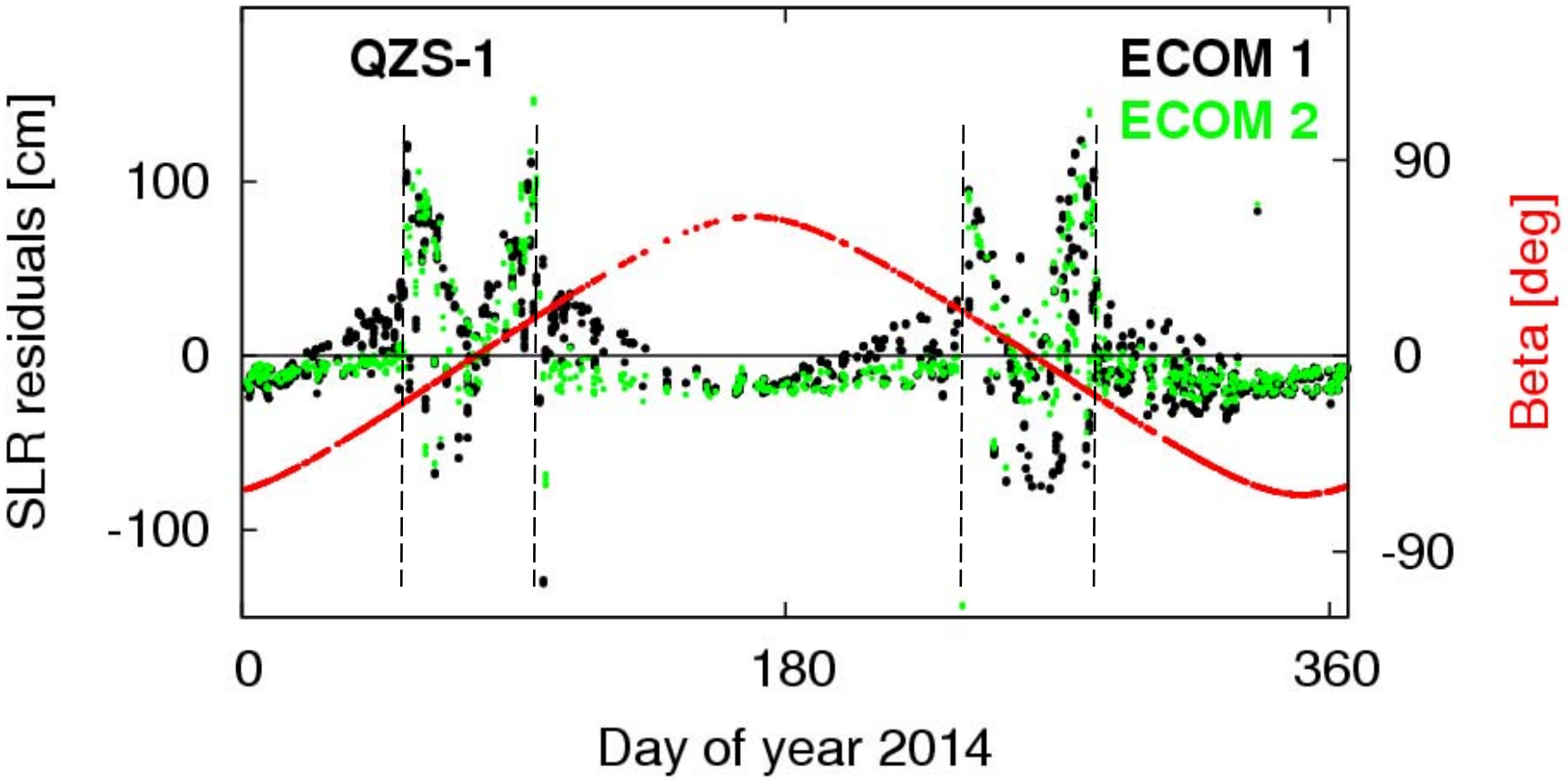
Impact of new ECOM on Galileo clock corrections



DOY 14/180: Beta-angle is low (i.e., cross-section of satellite body wrt. the Sun varies periodically during each orbital revolution)

=> Periodic signal caused by mis-modelled orbit is significantly reduced (+- 0.75 ns -> +- 0.15 ns)

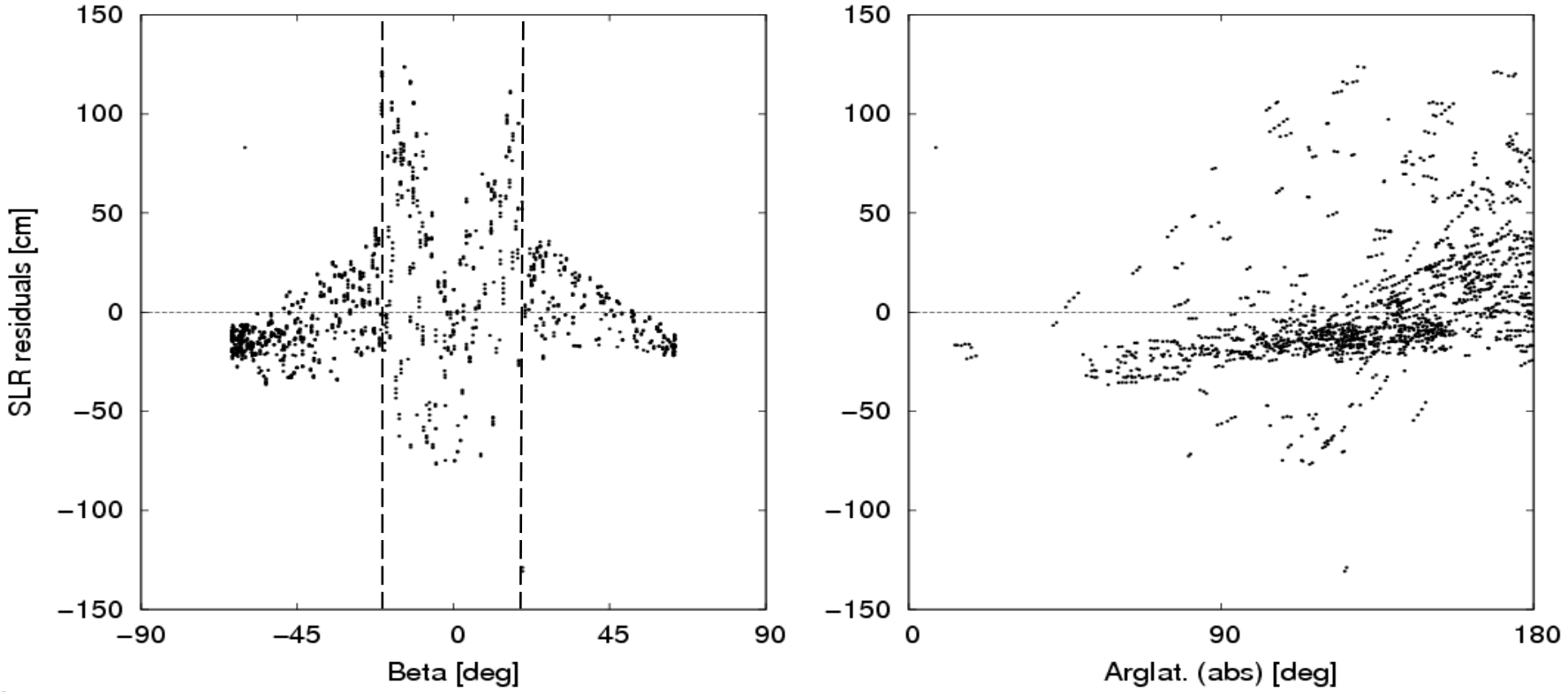
Impact of new ECOM on QZSS orbits



=> Improvement (dependency on Beta angle is reduced)

=> Unconsidered normal attitude mode dominates orbit errors at low Beta angles (< 20 degress)

Impact of new ECOM on QZSS orbits

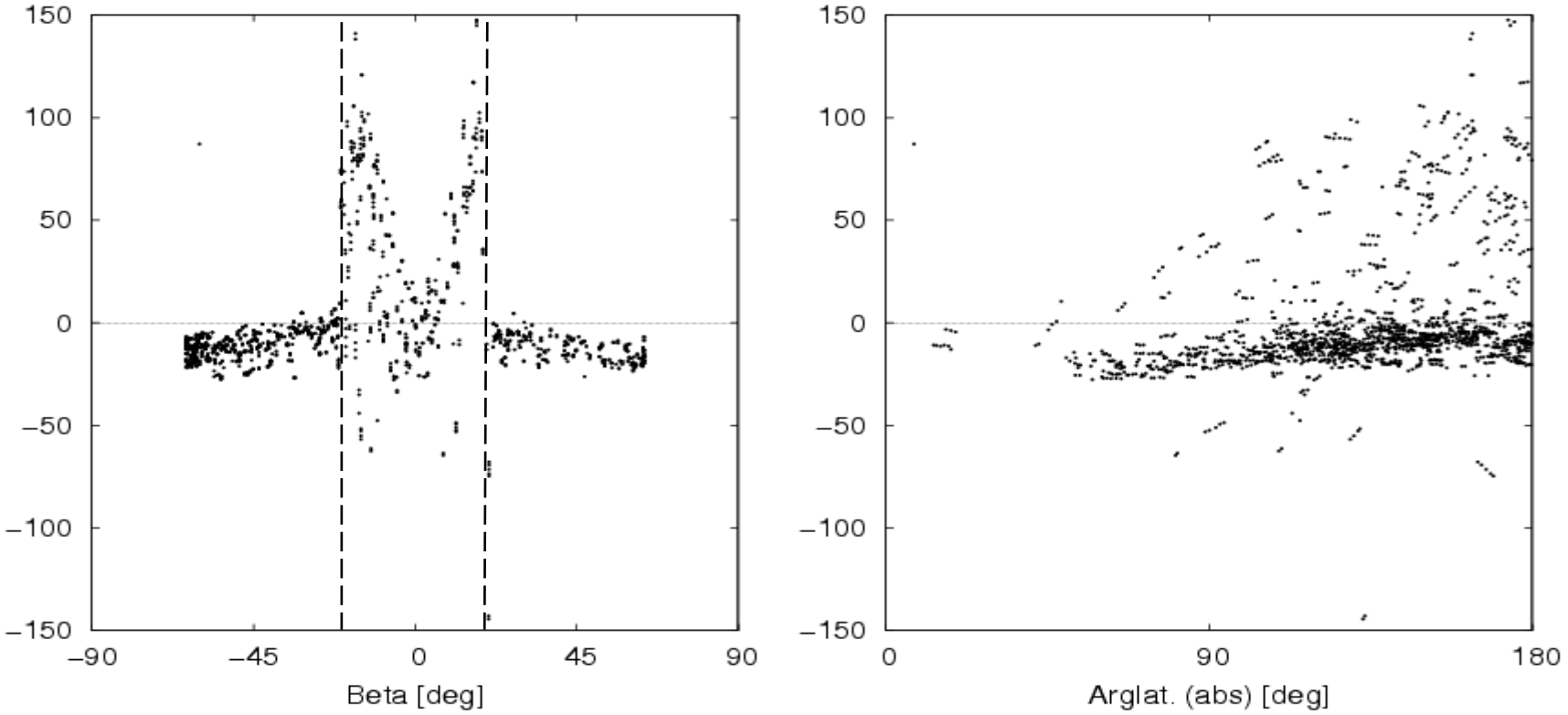


ECOM1:

=> abs(Beta) < 20 degrees: SLR residuals dominated by unconsidered orbit normal attitude mode

=> abs(Beta) > 20 degrees: correlation with Beta angle and argument of latitude

Impact of new ECOM on QZSS orbits



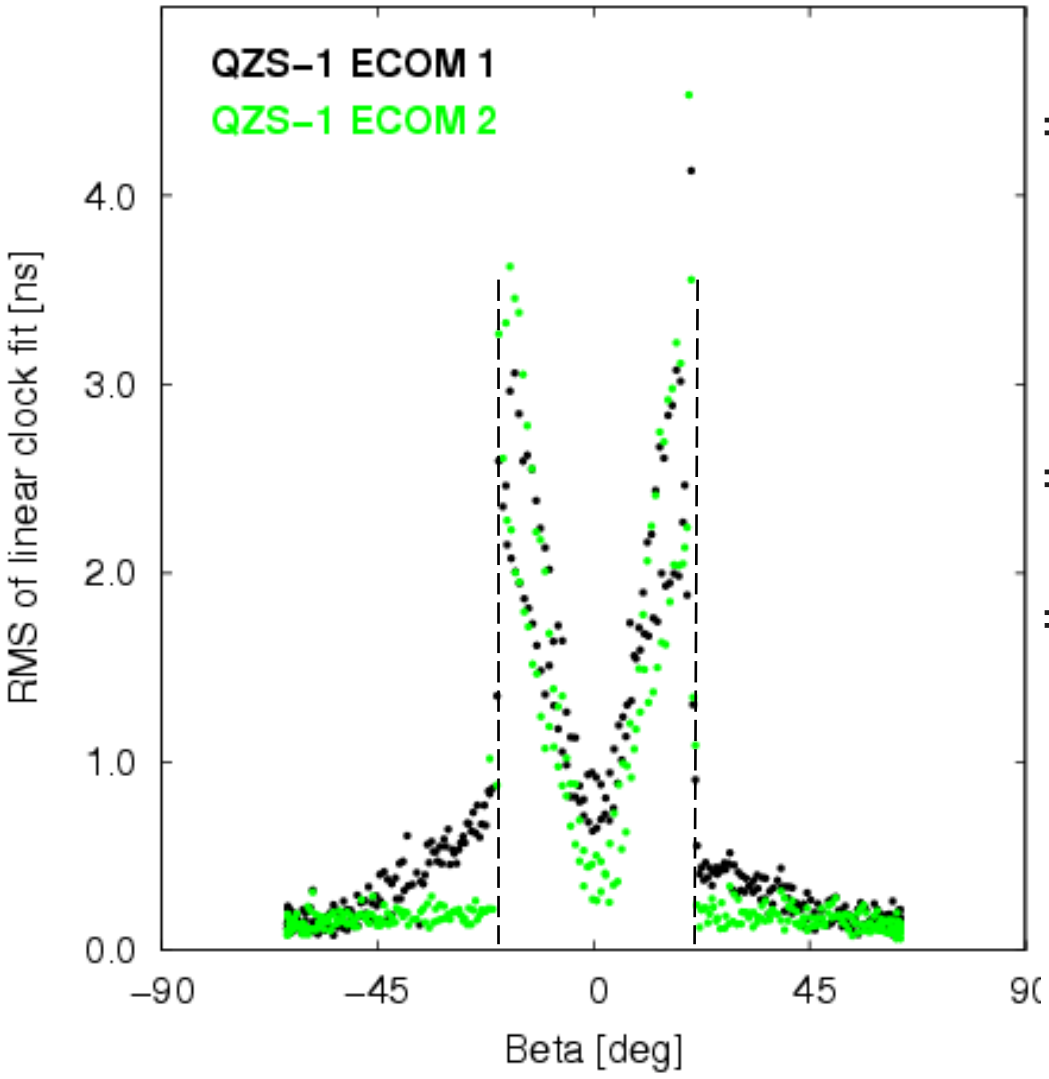
ECOM2:

=> abs(Beta) < 20 degrees: no big change

=> abs(Beta) > 20 degrees: systematics in the SLR residuals are reduced

=> SLR offset remains

Impact of new ECOM on QZSS clock corrections



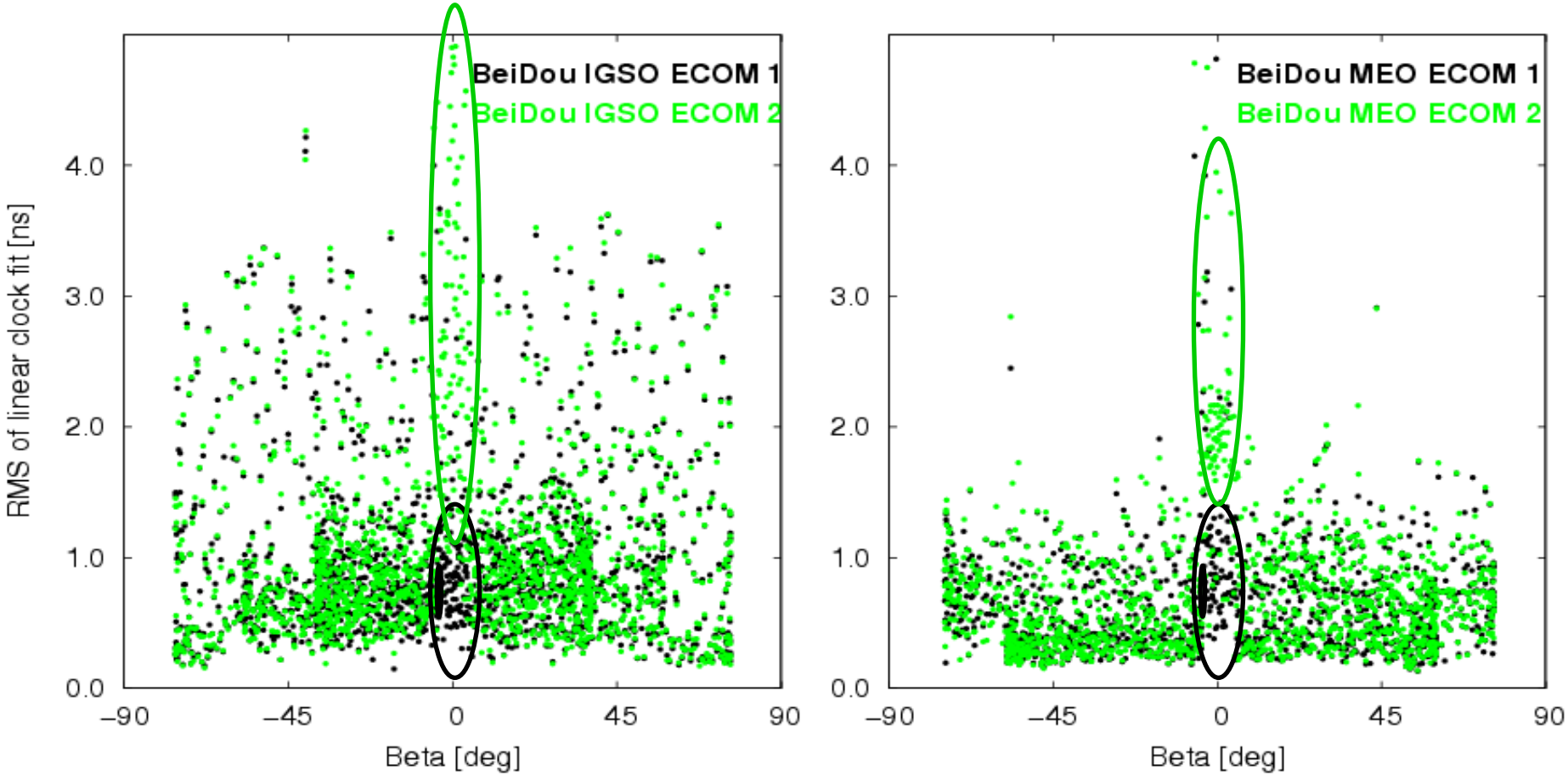
QZS-1:

=> abs(Beta) > 20 degrees: very good performance of satellite clock becomes obvious (RMS of linear fit <0.1 ns possible)

=> Clocks are suited for orbit validation

=> Orbit errors and unmodelled normal attitude are directly mapped into satellite clock estimates (see abs(Beta) <20 degrees)

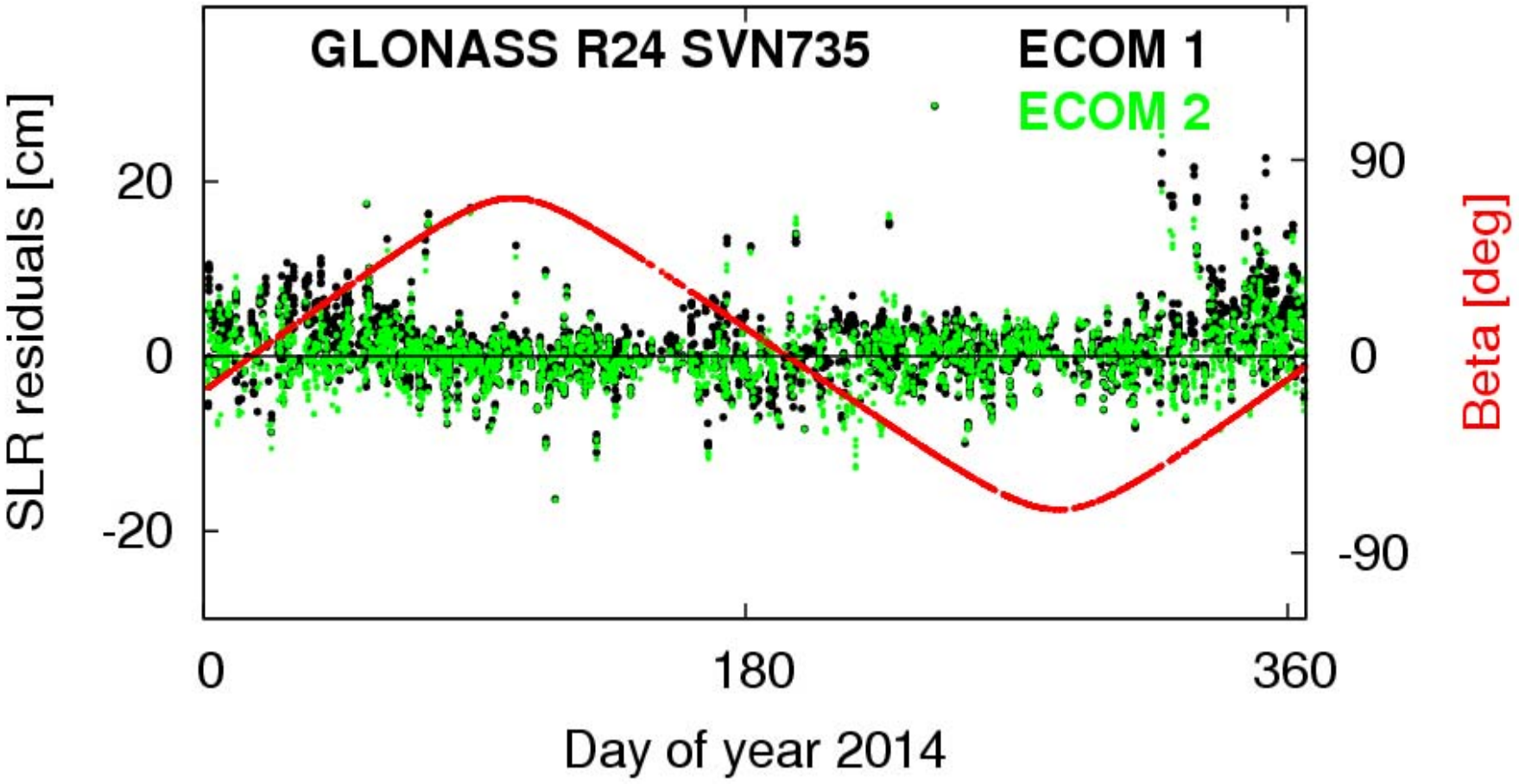
Impact of new ECOM on BeiDou clock corrections



=> No significant impact of new ECOM on BeiDou satellite clock corrections, but

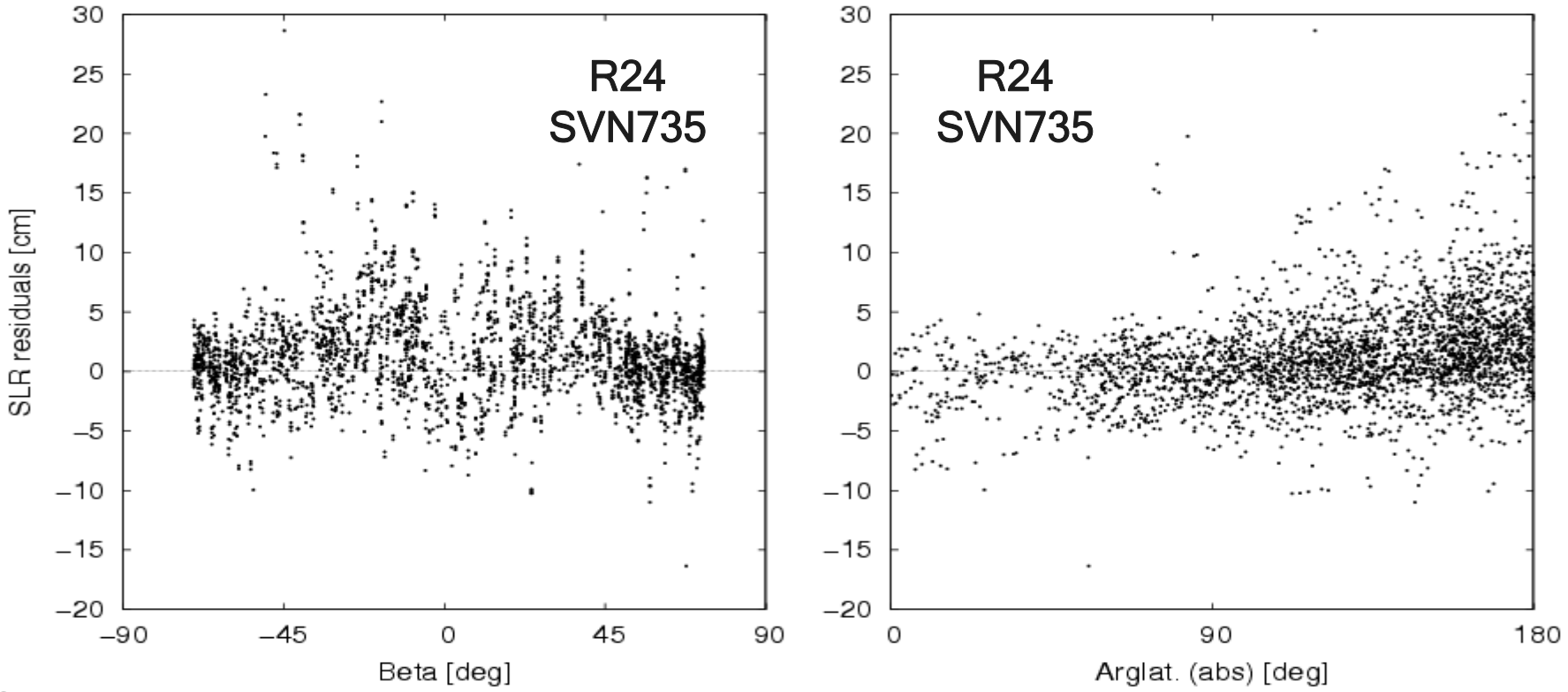
=> Increased RMS of clock fit for very small Beta angles (confirming changed attitude mode at abs(Beta) < 4 degrees)

Impact of new ECOM on GLONASS orbits



=> Moderate reduction of SLR residuals at low Beta angles for majority of satellites

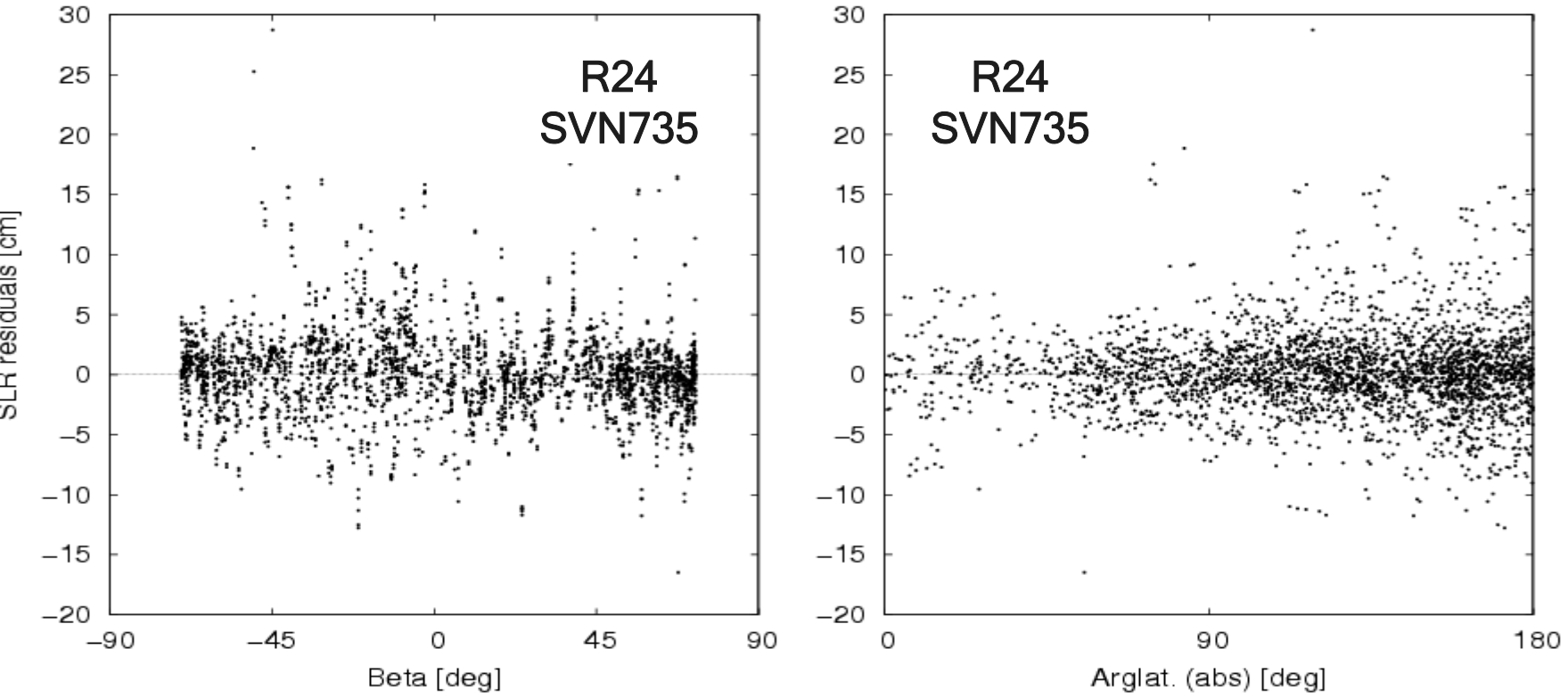
Impact of new ECOM on GLONASS orbits



ECOM1:

=> Moderate correlation of SLR residuals with Beta angle and argument of latitude

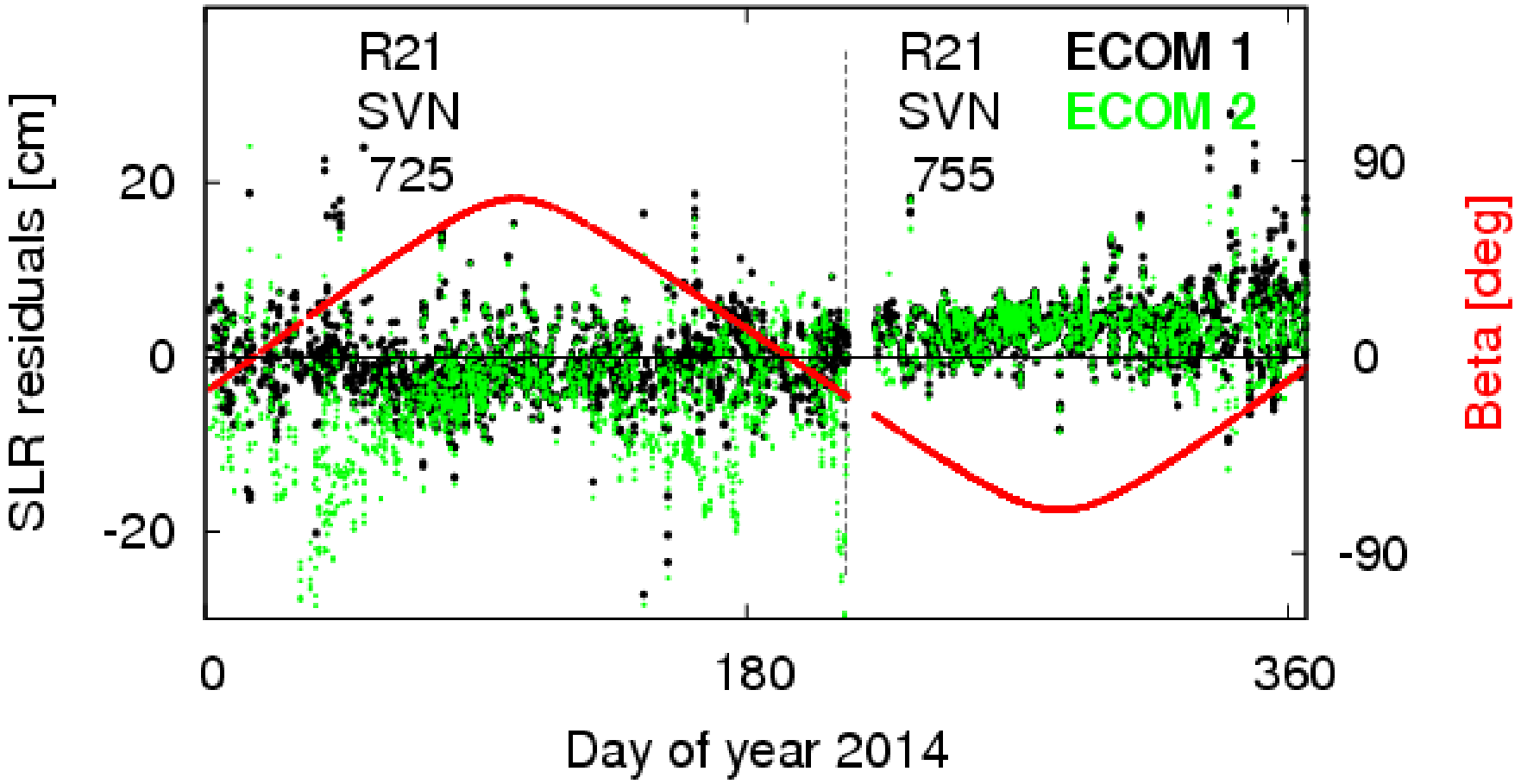
Impact of new ECOM on GLONASS orbits



ECOM2:

=> Systematics in the SLR residuals are reduced

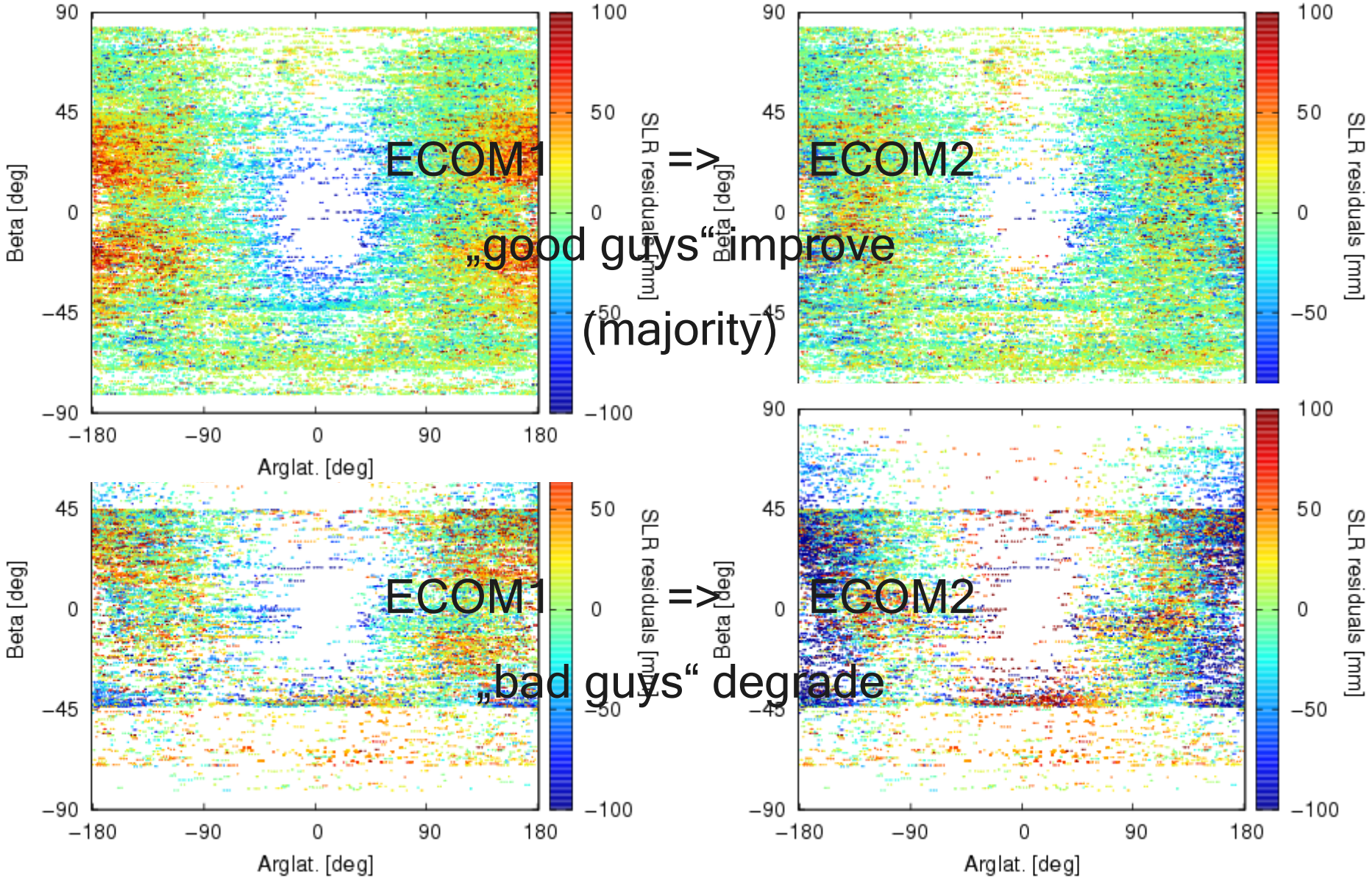
Impact of new ECOM on GLONASS - exceptions



=> ECOM2 does not work well for all GLONASS satellites

Impact of new ECOM on GLONASS orbits

Distribution of SLR residuals:



Orbit modeling: Summary

- Galileo: clear benefit from ECOM2
- QZSS: significant benefit from ECOM2 when in yaw attitude mode
- GLONASS: moderate benefit from ECOM2 for the majority of satellites; degradation for some satellites
- ECOM2 seems to be more sensitive to attitude mis-modellings
- Normal attitude steering mode at low beta-angles causes very large orbit errors if not correctly considered
- Stable satellite clocks (GPS IIF, Galileo, QZSS) are suited for orbit validation

Outlook

- Analysis of orbit model impact on different GNSS to be continued
- Analysis of attitude model impact on different GNSS
- Why do some GLONASS satellites react differently to the change of the radiation pressure model? (attitude keeping?, constraining of ECOM parameters necessary?)
- Estimation of satellite antenna phase center corrections (nadir and azimuth dependent)
- Future: Switch to RAPID mode

Thank you

for

your interest!